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EXPERIMENTAL STUDIES ON SM4308 AIRFOIL AT LOW REYNOLDS NUMBERS

S. Sudhakar[1], Shashank Mishra[2], G.Ramesh[1], K.T.Madhavan[1], Sajeer Ahmed[1]
[1] Experimental Aerodynamics division
CSIR-National Aerospace Laboratories, Bangalore-560017
[2] NAL Tech, Bangalore-560017

ABSTRACT

To provide better longitudinal stability at cruise for one of the MAV configurations developed at CSIR-NAL, a modified version of Eppler-61 airfoil designated as SM-4308 was used. The airfoil geometry was obtained using inverse design method of XFLR5 and aerodynamic characteristics of the modified airfoil were computed using XFLR5 at cruise Reynolds number of 160,000. To get aerodynamic characteristics at off design Reynolds number, an airfoil of chord 150mm was fabricated and tested in a 0.55m wind tunnel in the incidence range of -4 to 15 degree at low Reynolds numbers of 46,000, 67,000, 87,000 and 120,000. Surface pressures on the airfoil and total pressures in the wake were measured. From these, the aerodynamic characteristics in terms of lift, drag and pitching moment coefficients were computed and compared with those obtained on Eppler-61 airfoil earlier. Comparison shows lower pitching moment with the newer airfoil, associated with lower lift and drag coefficient. Variation of lift coefficient with incidence was observed to have lower lift curve slope with the stall occurring at lower angle. Also during positive angle of incidence no sudden change in lift was seen at lower Reynolds number of 47,000 and 67000 as observed on Eppler-61 airfoil. Flow on the airfoil was investigated in a 0.2m tunnel using smoke flow technique at lower Reynolds number of 67,000 and 87,000. Analysis of these photographs together with surface pressure variation on the upper surface shows the presence of bubble like structure on the SM-4308 compared to flow separation on Eppler airfoil. The early stall seen with SM-4308 airfoil was observed to be due to the bursting of bubble. Comparison of surface pressures computed using XFLR5 with free transition mode on SM-4308 airfoil showed nearly good agreement with experimental data.

Key words: Low Reynolds number, laminar separation bubble, transition

NOMENCLATURE

C_L	Lift coefficient
C_D	Drag coefficient
C_n	Coefficient of normal force
C_a	Coefficient of axial force
$C_{ML.E}$	Pitching moment coefficient about leading edge
$C_{Mc/4}$	Pitching moment coefficient about quarter chord
α-	Angle of incidence
α_{stall}	Stall angle of incidence
C_P	Coefficient of pressure
C_{PU}	Coefficient of pressure on upper surface
C_{PL}	Coefficient of pressure on lower surface
p	Local static pressure
p_∞	Free stream static pressure
q	Dynamic pressure in the wake
q_∞	Free stream dynamic pressure
x	Coordinate along the chord
y	Coordinate perpendicular to chord
c	Airfoil chord
Re	Chord Reynolds number

1. INTRODUCTION

Studies at low Reynolds number have generated lot of interest in the scenario of development of micro air vehicle for the consideration of both strategic and civil application. Experimental studies have been done to optimize the airfoil geometry and planform geometry to improve the performance from the aspect of increasing endurance and stability of the vehicle [1-4]. It is also observed that the performance using optimized airfoil/wing performance dependent on several factors like freestream turbulence, gust, and propeller effect [5].

Recently CSIR-National Aerospace Laboratories has initiated R&D activities at low Reynolds number with the objective of developing different configurations of MAV for the strategic purpose. Basic studies have been done on an Eppler 61 airfoil to get the understanding of flow at low speeds/Reynolds numbers and to validate the facility to take up further studies at low Reynolds numbers [6].Eppler 61 airfoil along with inverse Zimmerman has been selected to design one of the MAV configurations. These studies have shown that the airfoil geometry exhibits good performance in terms of lift and higher stall angle of 15° at cruise Reynolds number of 160,000 with good static stability but with large negative pitching moment at zero angle of incidence. In order to obtain a better stability with a lower negative pitching moment, Eppler 61 airfoil geometry was modified using inverse method of XFLR5 and new airfoil geometry was obtained and designated as SM4308. This airfoil has been used in the design of another MAV configuration [7]. Preliminary flight tests of this configuration have shown better stability of the airframe during flight. This airfoil has 4% camber and 8% thickness compared to 6.3% camber and 5.63% thickness for Eppler 61 airfoil. To carryout flight simulation studies aerodynamic characteristics of the airfoil were required at off design conditions and these were determined in the off design Reynolds number range of 47000 to 120000. Results of this study are reported in this paper and discussed with reference to the aerodynamic data of Eppler 61 airfoil. Geometrical details of the airfoils are shown in the Figure 1

2. EXPERIMENTAL DETAILS

Experiments were carried out on a 150mm chord SM-4308 airfoil in the 0.55m low speed tunnel at freestream velocity of 5, 7.5,10 and 13.5 m/sec corresponding to chord Reynolds number of 46k, 67k, 87k and 120k and in the angle of attack range of -4 to 15 deg. Freestream turbulence level in the free stream velocity range of 5 to 13.5 m/sec is within 0.1% of freestream velocity. The SM-4308 airfoil was embedded with 16 static pressure ports on the upper surface and 17 ports on the lower surface. The pressure ports on the upper and lower surface were located along 10 deg inclination line with included angle of 20 deg to minimize the flow interference from one port to the other port. The airfoil model was made of FRP and has span of 545mm and mounted between two walls of the tunnel. The last location of the static pressure port was at 85% chord as no pressure port beyond this could be located due to minimal thickness of the airfoil. Wake profile was obtained using a pressure rake placed at 1.2chord downstream of the trailing edge of airfoil. Surface pressures and wake pressures were measured using ESP scanners of range ±250mm of water. Freestream static and total pressures were measured using furnace manometer of range ±25mm water. Smoke flow visualization studies were carried out on both Eppler61 and SM 4308 airfoils of chord 150mm in a different tunnel having a test section size of 0.2m X 0.2m. Studies were done at Reynolds number of 67000 and 87000 at incidence of 4°, 6° and 8°.

3. DATA REDUCTION

Surface pressures measured were non-dimensionalized and expressed in terms of co-efficient of pressure (Cp).

$$C_p \equiv \frac{p - p_\infty}{q_\infty}$$

Using coefficient of pressures on upper and lower surface, normal force and axial force coefficients were computed.

$$C_n = \int_0^c (C_{pl} - C_{pu})dx$$

$$C_a = \int_0^c (C_{pu} - C_{pl})dy$$

Using these lift coefficient was computed using

$$c_l = c_n \cos\alpha - c_a \sin\alpha$$

Drag coefficient is computed by integrating wake velocity profile

$$C_d = 2\int \sqrt{\frac{q}{q_\infty}}\left(1 - \sqrt{\frac{q}{q_\infty}}\right) d\left(\frac{y}{c}\right)$$

Pitching moment co-efficient about the leading edge is computed using by

$$C_{MLE} = \frac{1}{c^2}\int_0^c (C_{pu} - C_{pl})xdx$$

$$+\frac{1}{c^2}\int_0^c (C_{pu} - C_{pl})ydy$$

Pitching moment co-efficient about the quarter chord is obtained by

$$C_{Mc/4} = C_{MLE} + C_n/4$$

4. RESULTS AND DISCUSSION

4.1Comparison of Aerodynamic Characteristics at Re= 46,000

A comparison of lift, drag and pitching moment characteristics for the SM 4308 and Eppler 61 airfoil is shown in Figure 3. Considerable difference in the variation of lift coefficient with incidence can be seen from the Figure. SM 4308 airfoil shows stall angle of 7 degree compared to 13 degree for Eppler 61 airfoil. Also no sudden jump in the lift characteristics is observed in the case of SM4308 airfoil and variation is nearly linear in the range of positive angle of incidence prior to stall. However a reduction of 50% in maximum lift is observed. Lower drag is seen in the pre stall region; and the aerodynamic efficiency expressed in terms of C_L/C_D is about 16 for both the airfoil occurring at incidence of 4 degree compared to 3 degree for Eppler 61 airfoil. Distinct variation in the pitching moment characteristics is seen. Though there is a reduction of 25% in the zero angle pitching moment for SM-4308, a tendency for instability is observed up to 4 degree incidence. These could be due to flow features being different on the two airfoils.

4.2 Comparison of Aerodynamic Characteristics at Re=67,000, 87,000, and 120,000

Similar variations can be observed from the test results obtained at Reynolds number of 67000 is shown in Figure 4a. Max C_L/C_D of 19 can be seen at incidence of 6 degree compared to 5 deg observed on Eppler 61 airfoil. Aerodynamic characteristics obtained at Reynolds number of 87000 shows similar trends as observed at 67,000(Figure 4b) with maximum lift coefficient increasing to 1.0 and stall angle increasing to 8deg. Pitching moment characteristics shows a further reduction in zero angle pitching moment by about 75% and the stability is observed to be tending towards neutral. A maximum C_L/C_D of about 31.5 is observed at incidence of 4degree compared to 38 at incidence of 9 degree for Eppler 61 airfoil. With increase in Reynolds number to 120,000 the maximum lift coefficient has remained invariant at C_L=1.0; zero pitching moment further decreases to about 85% of the Eppler-61 airfoil and its variation with incidence showing neutral stability (Figure 4c). A maximum C_L/C_D value of 35 at incidence of 6 degree is observed compared to C_L/C_D of 58 at 8 degree of incidence. In the range of Reynolds numbers tested drag coefficient is observed to be always lower. The above observations are summarized in the Table below:

Parameter	Re=46000		Re=67000	
	SM4308	Eppler61	SM4308	Eppler61
C_{Lmax}	0.78	1.4	0.92	1.7
C_{Dmin}	0.026	0.048	0.027	0.042
α_{stall}	7	13	7	14
$C_{Mc/4}$ α=0	-0.092	-0.12	-0.065	-0.16
$C_L/C_{D\ max}$	16	16	19	48

Parameter	Re=87000		Re=120000	
	SM4308	Eppler61	SM4308	Eppler61
C_{Lmax}	1.0	1.60	1.03	1.55
C_{Dmin}	0.018	0.062	0.015	0.038
α_{stall}	8	14	8	-
$C_{Mc/4}$ α=0	-0.043	-0.16	-0.028	-0.16
$C_L/C_{D\ max}$	31.5	38	35	58

A summarized plot of the above results is shown Figure 4.d

As seen from the Figure 4d. and table the new airfoil SM 4308 shows an improved performance in terms of minimum drag and pitching moment coefficient and reduction in performance in other parameters such as maximum lift coefficient, C_L/C_D and stall angle.

4.3. Smoke Flow Field Patterns

Smoke flow visualization studies were done on both airfoils at chord Reynolds number of 67000, 87000 at incidence of 4, 6, and 8 degree and flow patterns captured are shown in Figure 5. At both Reynolds numbers flow separation can be seen on Eppler airfoil at all the incidence angles tested. and with increase in incidence angle separation point moves upstream. In the case of SM 4308, at low Reynolds number of 67k flow separates and reattaches on the surface enclosing a bubble. The separation point moves upstream along with the bubble and probably burst with an increase in incidence to 7 degree leading to stall associated with decrease in lift as seen earlier from the Figure (Figure 4a). The surface pressure variations on both the airfoil surface are shown in Figure 6 confirms the flow variation seen in the smoke flow pattern.

4.4 Prediction using XFLR5

On both the airfoils surface pressures were predicted using XFLR5 freeware with free transition mode [8]. These are compared with pressures obtained through experiments. Comparison is done at incidence of 6 degree and Reynolds number of 87000(Figure 7). For SM4308 airfoil the pressure data on the lower surface matches closely with the predicted values. However on the upper surface predicted and experimental data shows the presence of bubble like structure. But the location and length of the bubble observed to be different. Also separation point is observed to occur early on the airfoil surface and further reattachment with the shorter length of bubble. For Eppler 61 airfoil the experimental data on the upper surface is slightly different beyond 50% chord. These observations show that the freeware can be used to get the preliminary design values; but have to be validated using experimental data.

5. CONCLUSIONS

An experimental study is carried out to get the aerodynamic characteristics of SM4308 airfoil, a modified version of Eppler-61 airfoil in the Reynolds number range of 47,000 to 120,000. This airfoil was designed to provide better stability in the flight envelope of the vehicle using inverse method of XFLR5. Aerodynamic characteristics in obtained through measurement of surface pressures on the airfoil and total pressure of wake. A comparison of data with that obtained on Eppler 61 airfoil showed an improvement in the aerodynamic performance of the airfoil in terms of minimum drag and reduction of pitching moment. Flow visualization studies shows presence of bubble on the airfoil and burst of bubble leads to occurrence of stall at lower incidence angle compared to Eppler-61 airfoil.

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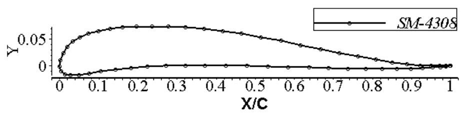
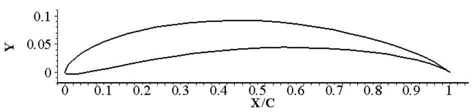


SM-4308



Eppler-61

Figure 1.Geometric details of airfoils

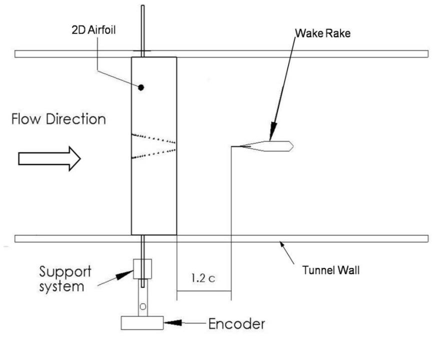
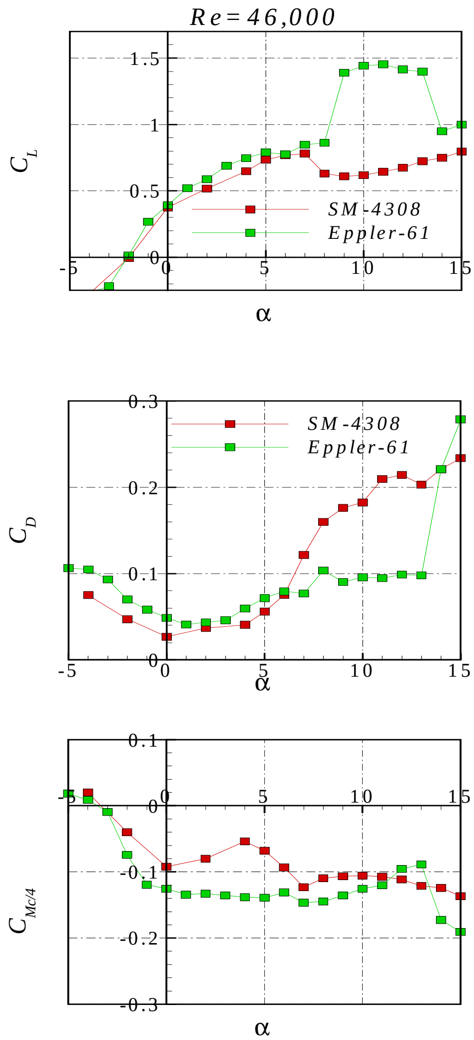


Figure 2.Experimental Setup



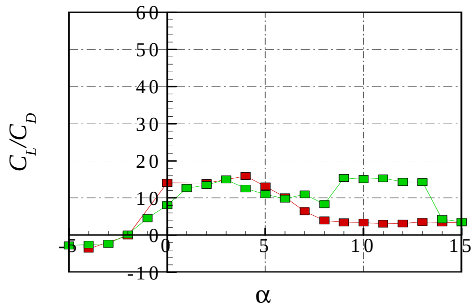
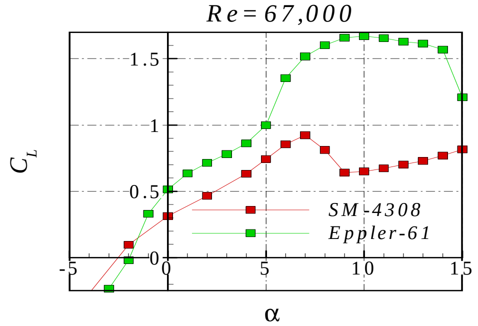
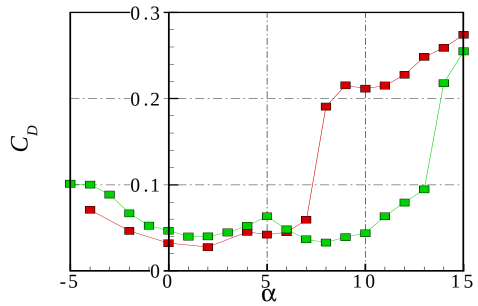
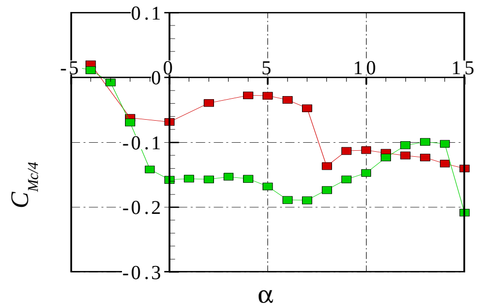


Figure 3. Aerodynamic characteristics at Re=46,000

Re = 67,000







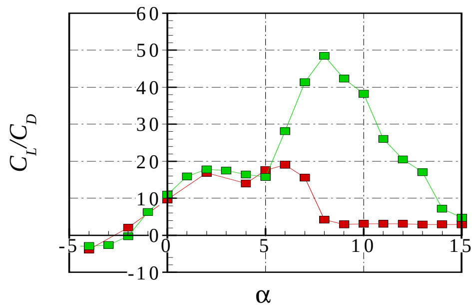
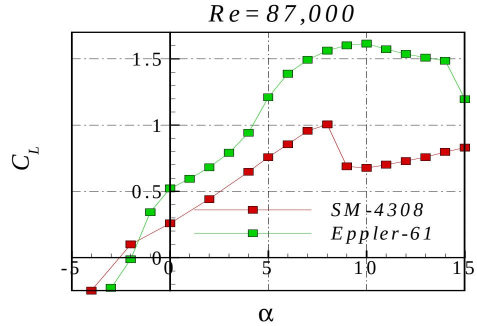
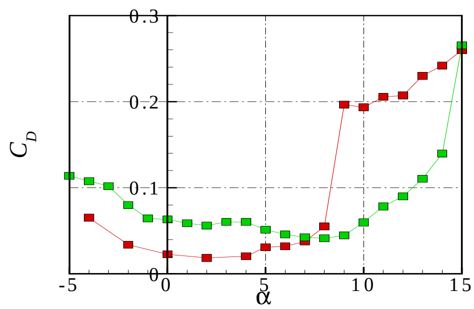
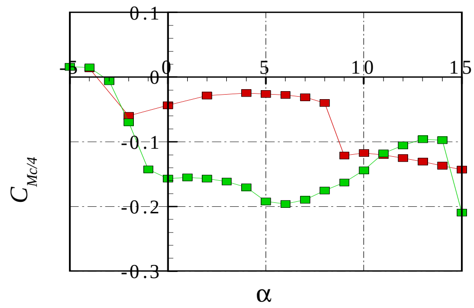


Figure 4a

Re = 87,000







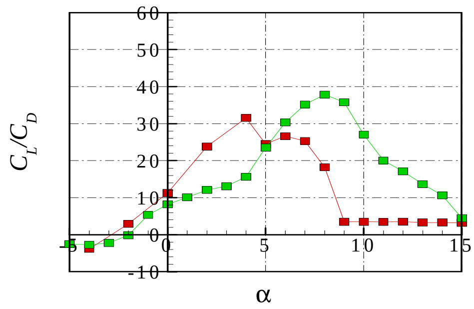
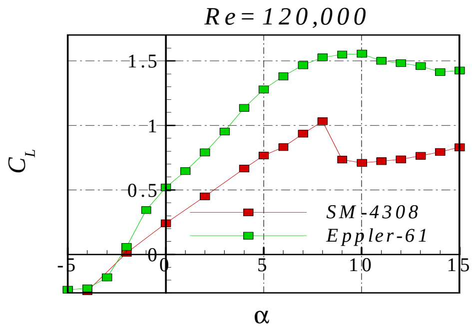
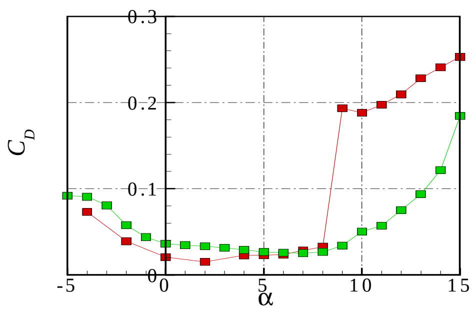


Figure 4b





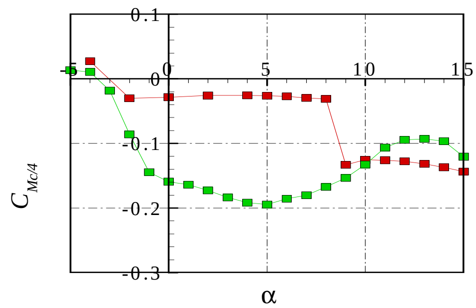
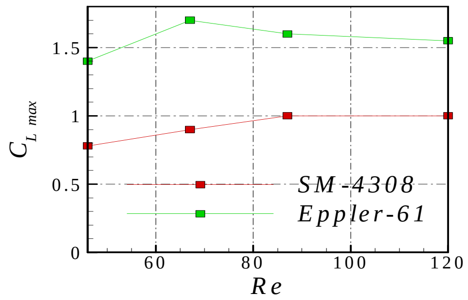


Figure 4c



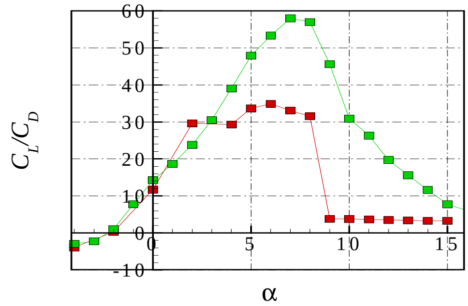
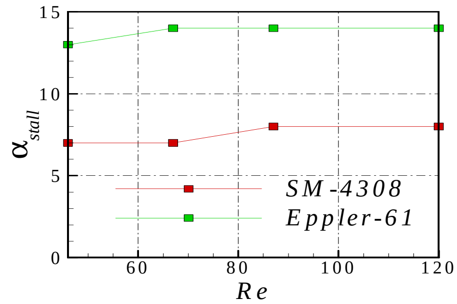
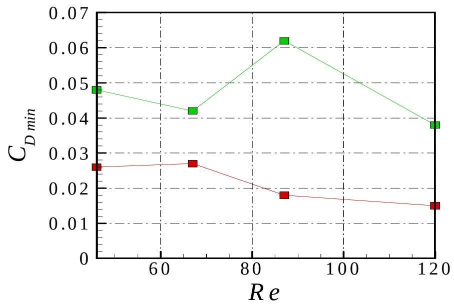
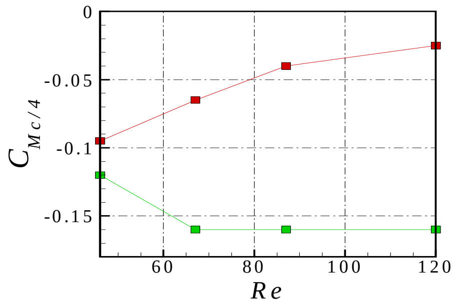


Figure 4d







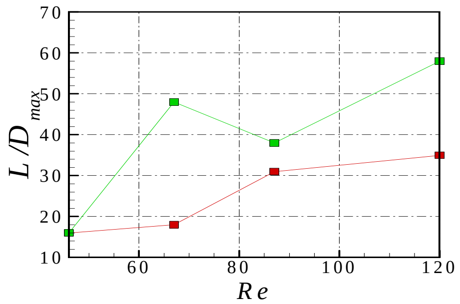
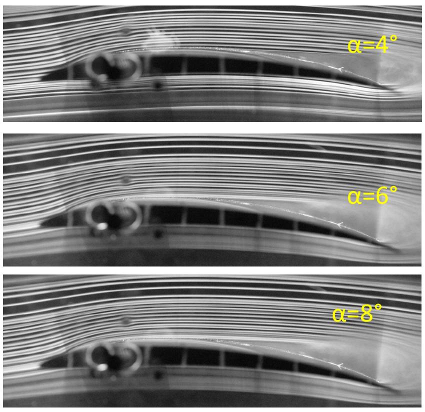


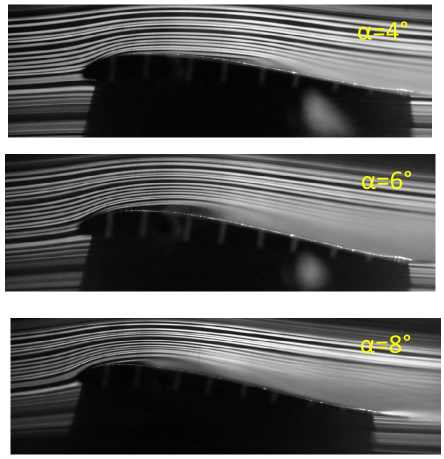
Figure 4d continued

Figure 4. Comparison of aerodynamic characteristics

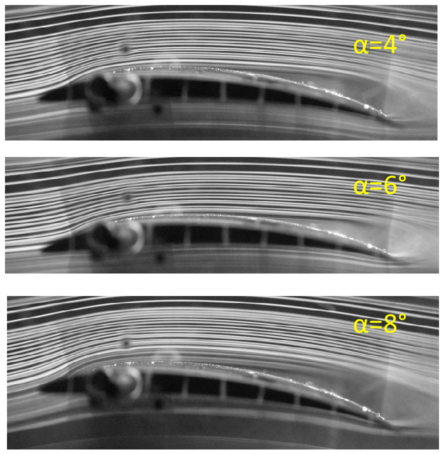


Eppler-61 Re=67,000

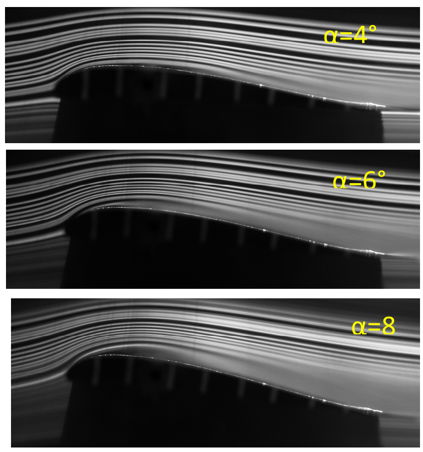
Figure 5. Flow pattern on Eppler-61 and SM-4308 airfoils



SM 4308; Re=67,000



Eppler-61 Re=87,000



SM 4308; Re=87,000

Figure 5. continued

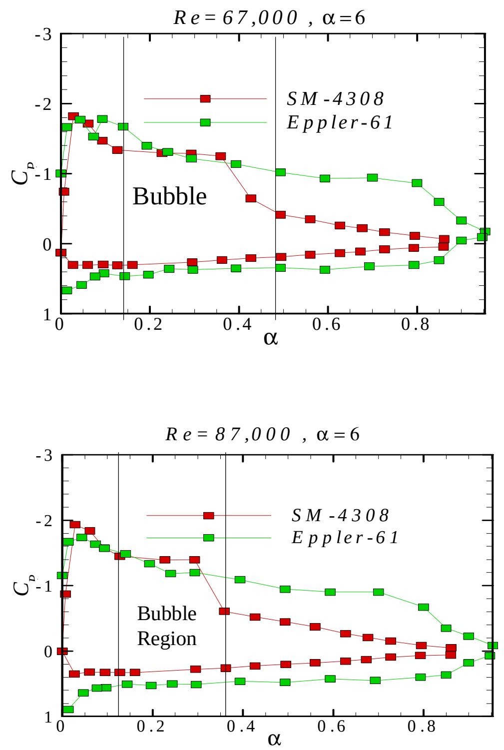


Figure 6. Pressure distribution on SM-4308 and Eppler-61 airfoils

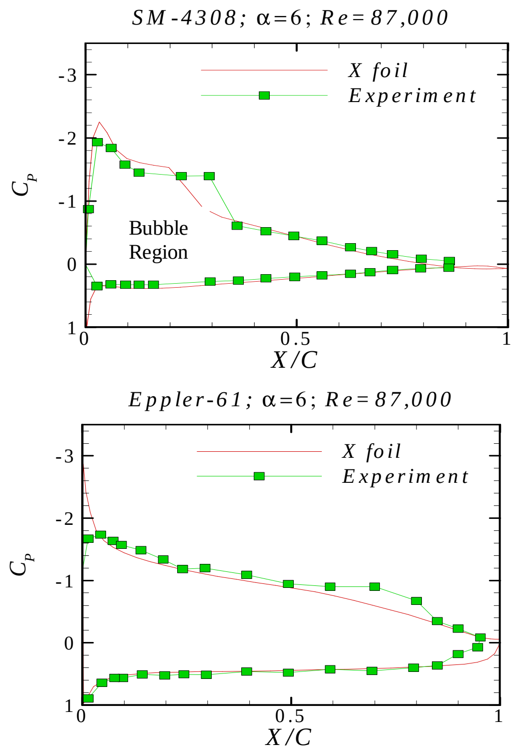


Figure 7. Comparison of pressure distributions